New alloys key to efficient energy and lighting

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A recent advance by Arizona State University researchers in developing nanowires could lead to more efficient photovoltaic cells for generating energy from sunlight, and to better light-emitting diodes (LEDs) that could replace less energy-efficient incandescent light bulbs.

Electrical engineers Cun-Zheng Ning and Alian Pan are working to improve quaternary alloy semiconductor nanowire materials.

Nanowires are tens of nanometers in diameter and tens of microns in length. Quaternary alloys are made of semiconductors with four elements, often made by alloying two or more compound semiconductors.

Semiconductors are the material basis for technologies such as solar cells, high-efficiency LEDs for lighting, and for visible and infrared detectors.

One of the most critical parameters of semiconductors that determine the feasibility for these technologies is the band gap. The band gap of a semiconductor determines, for example, if a given wavelength of sun light is absorbed or left unchanged by the semiconductor in a solar cell.

Band gap also determines what color of light an LED emits. To make solar cells more efficient, it's necessary to increase the range of band gaps.

Ideally, the highest solar cell efficiency is achieved by having a wide range of band gaps that matches the entire solar spectrum, explains Ning, a professor in the School of Electrical, Computer and Energy Engineering, a part of ASU's Ira A. Fulton Schools of Engineering.

In LED lighting applications, he says, more available band gaps means more colors can be emitted, providing more flexibility in color engineering or color rendering of light.

For example, different proportions of red, green and blue colors would mix with different white colors. More flexibility would allow white color to be adjusted to suit various situations, or individual preferences.

Similarly, Ning says, detection of different colors requires semiconductors of different band gaps. The more band gaps that are available, the more information can be acquired about an object to be detected. Thus, all of these lighting applications can be improved by having semiconductors with a wide range of band gaps.

The researchers say the hurdle is that every manmade or naturally occurring semiconductor has only a specific band gap.

One standard way to broaden the range of band gaps is to alloy two or more semiconductors. By adjusting the relative proportion of two semiconductors in an alloy, it's possible to develop new band gaps between those of the two semiconductors.

But accomplishing this requires a condition called lattice constant matching, which requires similar inter-atomic spaces between two semiconductors to be grown together.

"This is why we cannot grow alloys of arbitrary compositions to achieve arbitrary band gaps," Ning says. "This lack of available band gaps is one of reasons current solar cell efficiency is low, and why we do not have LED lighting colors that can be adjusted for various situations."

In recent attempts to grow semiconductor nanowires with "almost" arbitrary band gaps, the research team led by Ning and Pan, an assistant research professor, have used a new approach to produce an extremely wide range of band gaps.

They alloyed two semiconductors, zinc sulfide (ZnS) and cadmium selenide (CdSe) to produce the quaternary semiconductor alloy ZnCdSSe, which produced continuously varying compositions of elements on a single substrate (a material on which a circuit is formed or fabricated).

Ning says this the first time a quaternary semiconductor has been produced in the form of a nanowire or nanoparticle.

By controlling the spatial variation of various elements and the temperature of a substrate (called the dual-gradient method), the team produced light emissions that ranged from 350 to 720 nanometers on a single substrate only a few centimeters in size.

The color spread across the substrate can be controlled to a large degree, and Ning says he believes this dual-gradient method can be more generally applied to produce other alloy semiconductors or expand the band gap range of these alloys.

To explore the use of quaternary alloy materials for making photovoltaic cells more efficient, his team has developed a lateral multi-cell design combined with a dispersive concentrator.

The concept of dispersive concentration, or spectral split concentration, has been explored for decades. But the typical application uses a separate solar cell for each wavelength band.

With the new materials, Ning hopes to build a monolithic lateral super-cell that contains multiple subcells in parallel, each optimized for a given wavelength band. The multiple subcells can absorb the entire solar spectrum. Such solar cells will be able to achieve extremely high efficiency with low fabrication cost. The team is working on both the design and fabrication of such solar cells.

Similarly, the new quaternary alloy nanowires with large wavelength span can be explored for color-engineered light applications.

The researchers have demonstrated that color control through alloy composition control can be extended to two spatial dimensions, a step closer to color design for direct white light generation or for color displays.

More information:
Related research by Ning and his colleagues has been reported in these articles:

* Pan, R. Liu, M. Sun and C.Z. Ning, Spatial Composition Grading of Quaternary ZnCdSSe Alloy Nanowires with Tunable Light Emission between 350 and 710 nm on a Single Substrate, ACS Nano, pubs.acs.org/doi/abs/10.1021/nn901699h
* Pan, R. Liu, M. Sun and C.Z. Ning, Quaternary Alloy Semiconductor Nanobelts with Bandgap Spanning the Entire Visible Spectrum, J. Am. Chem. Soc, 131, 9502 (2009), DOI: 10.1021/ja904137m , pubs.acs.org/doi/abs/10.1021/ja904137m
* C.Z. Ning, A. Pan, and R. Liu, Spatially composition-graded alloy semiconductor nanowires and wavelength specific lateral multi-junctions full-spectrum solar cells, Proceedings of 34th PVSC, IEEE, 001492(2009).

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